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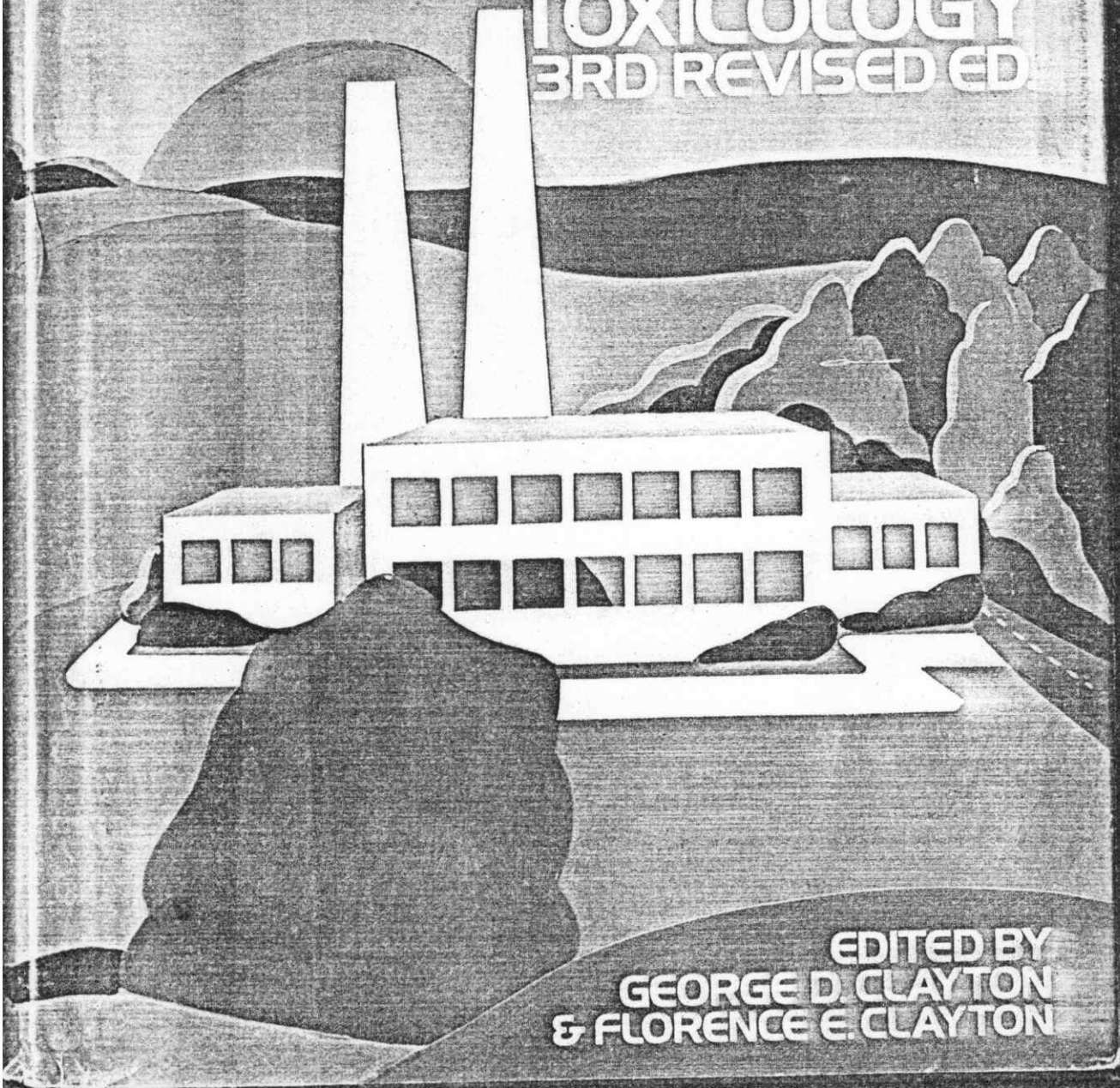
VOLUME I:
GENERAL PRINCIPLES

PATTY'S INDUSTRIAL HYGIENE AND TOXICOLOGY

3RD REVISED ED.



EDITED BY
GEORGE D. CLAYTON
& FLORENCE E. CLAYTON

of 0.001 to 0.002°C per second. Such a perception threshold depends on the size of the skin area irradiated by IR as well as the density of thermoreceptors in that area. The thresholds for perceiving warmth decrease with increasing area of irradiated skin, but apparently the thresholds bear no relation to the absolute temperature of the skin. On the other hand, precooled skin can be rapidly heated without eliciting the sensation of warmth (3).

Unlike the thresholds of warmth sensation, the thresholds for pain appear to be directly dependent on skin temperature, despite wide individual variation in their values (17). Wertheimer and Ward (33) have recorded a range of skin temperature pain thresholds of 44.1 to 44.9°C, depending on body site. The experiments of Hardy et al. (34) indicate that the threshold of pain is reached when the skin temperature is raised to 45°C (44.5 ± 1.3°C). The same value also appears to be critical for producing a skin burn. Pain thresholds therefore appear to be related to skin temperature, whereas the extent of tissue damage is dependent on skin temperature and duration of exposure.

3.3 Measurement of Infrared Radiation

An almost unlimited variety of IR instrumentation is available to the industrial hygienist: spectrophotometers, radiation pyrometers, stationary or scanning radiometers, and other equipment. The various detectors usually fall into one of two categories:

1. *Thermal detectors,* where absorbed energy heats the detector, which in turn causes a change in the properties of the detector material. Response is to all IR wavelengths, but the response time is slow. Typical examples are thermopiles, thermocouples, liquid crystals, bolometers, and pyroelectric crystals.
2. *Quantum detectors,* where all incident photons are sufficiently energetic to free a bound electron. Response is to a limited range of IR wavelengths, but response time is fast. Examples of this type of detector are photodiodes, photomultiplier tubes, and semiconductor devices such as gallium arsenide diodes.

4 VISIBLE RADIATION

From the industrial hygiene standpoint the use of visible wavelength radiations generally involves two considerations: (1) proper lighting practices to achieve a pleasant visual environment and the efficient performance of tasks that require optimum visual acuity, and (2) the control of radiation to prevent damage to the human body, usually the eyes and skin. The first subject is covered in considerable detail in Chapter 13; the second is considered in this section.

The visible portion of the electromagnetic spectrum consists of a very narrow band of wavelengths between the ultraviolet and the infrared. The photon energies associated with the visible wavelength range of 0.38 to 0.75 μm lie between 3.1 and 1.65 eV.

These energy levels are rather low and innocuous in terms of producing direct biological effects on the skin surfaces of the human body, however radiation in the 0.38 to 0.75 μm range acts on a body organ that is uniquely and exquisitely designed to transduce the incident photons into intelligible vision by means of complex and incompletely understood photochemical reactions. This exquisite organ is the retina of the eye. The photoreceptors of the incident photons are the rods and cones. The differences in function of these two receptor systems are worthy of note. Cones respond to higher levels of ambient illumination than do the rods, hence their level of activity is normally greater during daylight hours. The cones also come into play for the discrimination of fine visual detail. Since the rods are in greater numerical abundance in the peripheral paramacular area of the retina, they provide a wide area peripheral view of the visual field. The rods and cones respond differently to different wavelengths: the spectral luminous efficiency for rods is at a wavelength of 0.510 μm, whereas the peak efficiency of the cones is at 0.555 μm (35). The retina is able to adapt to the wide range of light intensities, but the adaptation time varies with the luminous flux. Light adaptation occurs within a short time duration, usually of the order of seconds, whereas dark adaptation may require more than an hour.

Visible light is not hazardous to the eyes under ordinary circumstances, even when high intensity light sources are encountered. For example, the adaptation of the eye to high intensity sunlight by such mechanisms as restricted pupil size, light adaptation, partial closing of the eyelids (squinting), blinking, and shading of the eyes by the eyebrows and periorbital socket, are all usually sufficient to prevent excessive radiation from reaching the retina. On the other hand, certain conditions involving exposure to light may produce significant hazards for humans. For example, if light is pulsed or gated at a frequency near the alpha rhythm (brain function), certain light-sensitive individuals may experience an epileptiform seizure. The effect may be produced when such persons observe a pulsating light pattern such as flickering sunlight coming through a stand of trees as the light is observed from a moving vehicle, or when watching a pulsed light pattern from a television set. In some cases it is the pattern of light generation rather than its brightness that is critical to the production of seizures. Flash blindness is another condition that may result from exposure to high intensity light sources. Flash blindness is caused by the bleaching of visual pigments that produce an "afterimage" or temporary blind area (scotoma) in the field of vision. The greater the light intensity and time of exposure, the more persistent will be the afterimage. If the original stimulation by a high intensity light source is sufficient to completely obliterate focused perception, some protracted period of time may be required before normal visual function is restored. The sun may damage the retina when viewed without proper protection; eclipse blindness is a familiar example, where retinal damage is caused by exposing the eye to a combination of excessive visible and IR radiations.

On a lesser scale, ordinary glare caused by improper placement of light sources (fixtures) may produce severe visual discomfort and may represent a safety hazard because of interference with visual performance. A more serious condition is one in which a veil-

ing glare may be temporarily superimposed on the retinal image, obscuring one's ability to discriminate details in the object being viewed. Such a condition exists on a more permanent basis in persons with cataracts.

High intensity light sources such as lasers, flashbulbs, spotlights, welding arcs, and carbon arcs can produce retinal burns under appropriate viewing conditions. Because of its coherent properties, a laser beam may be focused to an extremely small diameter. This results in the creation of highly intense beams of light, an obvious hazard to personnel.

Of the factors that have entered into the development of acceptable exposure levels for high intensity light sources, three seem to be of special importance.

1. The magnification factor of the eye as light passes through and is focused by the cornea and lens is of the order of 10^5. This means that the acceptable irradiance (W/cm^2) and the radiant exposure (J/cm^2) at the retina must have much greater numerical values than those present in front of the cornea where the industrial hygienist makes his field measurements. Permissible exposure levels are those which enter or impinge upon the eye at the cornea.
2. Acceptable exposure levels for wavelengths in the near infrared and infrared are somewhat less stringent than those for the visible wavelengths, whereas exposure levels for wavelengths in the blue and ultraviolet are more stringent, probably because of the photochemical mechanisms coming into play at the shorter wavelengths.
3. When exposed to a highly intense light source, most persons exhibit an "aversion response," that is, a tendency, to blink and turn the eyes and head. Presumably the elapsed time before the aversion response occurs gives some indication of the exposure time to be considered in establishing an exposure limit. In the case of the ANSI standard (36), the aversion time has been assigned a value of 0.25 second. The use of the aversion response concept in establishing safety guidelines for exposure to visible radiations has drawn criticism from some quarters because not all persons exhibit such a response. On the other hand, to establish safety standards strictly on the basis of experiments that irradiate the eyes of sedated animals whose eyelids are immobilized in an open position, to receive radiation pulses in excess of 0.25 second duration, means that practical conditions and normal physiologic response are ignored.

5 LASERS

Lasers are widely used for a variety of purposes such as alignment, welding, trimming, spectrophotometry, interferometry, flash photolysis, fiber optics communications systems, nuclear fusion experimentation, and surgical removal or repair procedures. A comprehensive review of medical and biological applications may be found in Wolbarsht (37).

The word "laser" is the acronym for "light amplification by stimulated emission of radiation." When an atom has been stimulated into an excited state, it may lose its

excess energy through sp
energy at a specific wave
an applied electromagnet
tion, and polarization as
stimulated emission. Sin
mally greater than the n
most radiations is usuall
field. However if the p
number to energy levels
by the stimulated emissi
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(gain) will be proportio
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The energy stimulatic
level (ground state, broa
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before they return to t
specific frequency. The
between the metastabl
constant.

Many gas lasers an
operate in a four-level s
a three-level system) ar

Figure 11.2 depicts
from ground state to a
tromagnetic radiation,
the case of most gas la
are brought to level 2,
mulation of atoms occu
the dumping of atoms
passing from level 2 to
laser. The relative ma
tions of atoms at each l

Stimulated emission
(38). Since the early 1
from the ultraviolet to
which stable, single-f
system can be operate
1.15, or 3.39 μm, dep
neon systems is of the

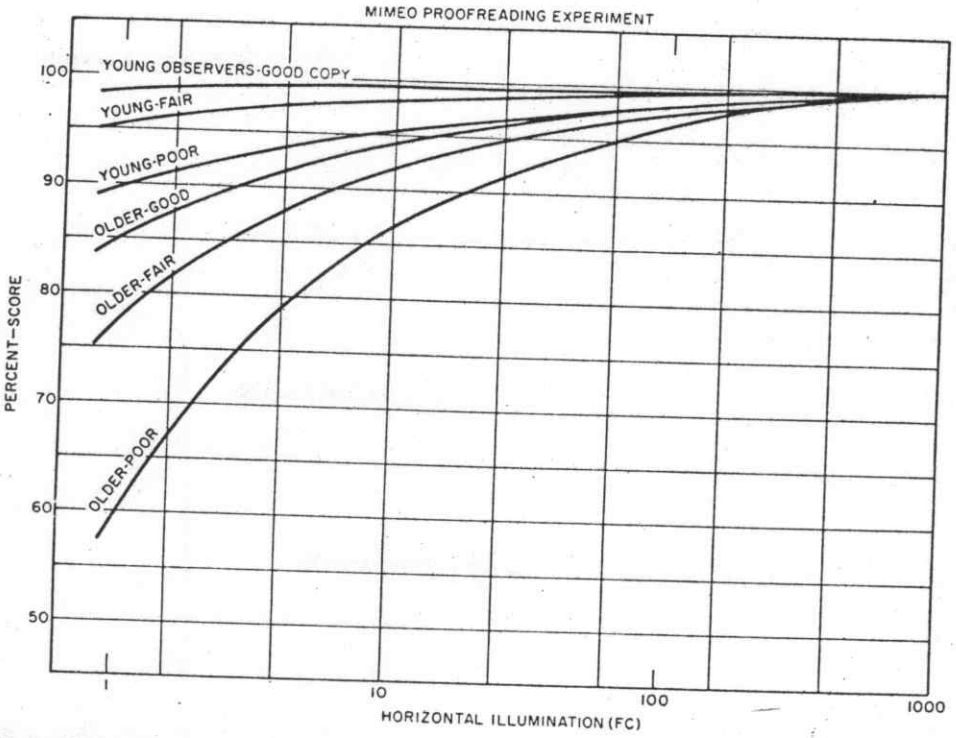


Figure 13.30 Relative results of "mimeograph" proofreading experiment from Figure 13.24 showing effect of quality of mineographed material and age of observers.

desks, in comparison to the light coming from wider angles (25, 26), which does not cause glossy reflection toward the eye (Figure 13.41). Study of the angular reflection of a typical task (pencil handwriting) has resulted in a determination of the effectiveness of light coming toward the task from various angles (27). This effectiveness is represented in Figure 13.42, where the length of the radial lines indicates the relative effectiveness of light approaching the task in revealing the details of that task. This average effectiveness holds for light approaching from every direction of the compass (i.e., 360° in azimuth including body shadow). It will be noted that the maximum occurs at 75° with the vertical, indicating that the light from walls and windows is very important in rendering more effective visibility of the task. (The reflectance of the walls should not be greater than 60 percent to avoid glare.)

6 EFFECT OF SURROUNDINGS: TRANSIENT ADAPTATION

The eyes are constantly scanning both the details of the task at hand and the immediate surroundings of the rest of the room. Time-lapse photography of office workers shows

Figure 13.31 Relation b
various sizes (5).

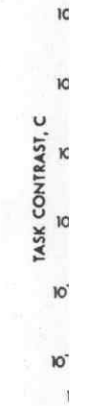


Figure 13.32 Plot of the
required at different leve
luminous disk exposed f
terion function (values of

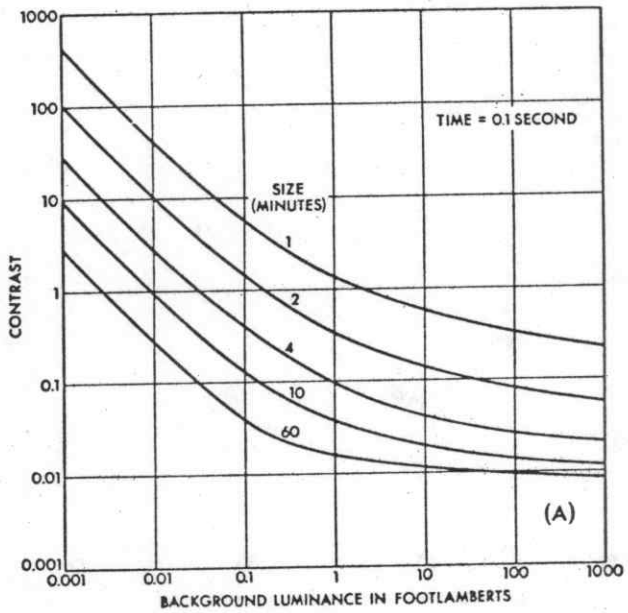


Figure 13.31 Relation between threshold contrast and background luminance for objects of various sizes (5).

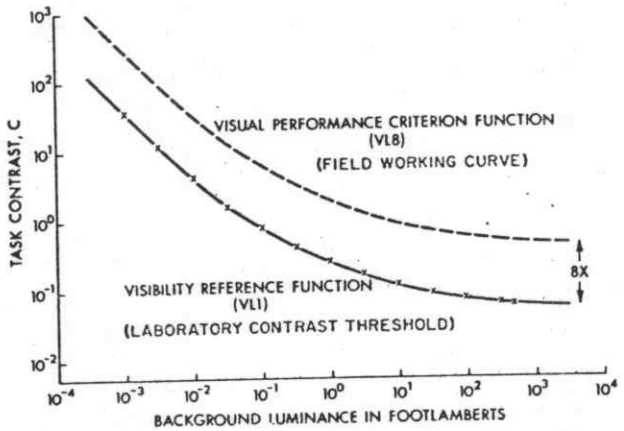


Figure 13.32 Plot of the Visibility Reference Function (solid curve) representing task contrast required at different levels of task background luminance to achieve threshold visibility for a 4′ luminous disk exposed for 0.2 second.The dashed curve represents the visual performance criterion function (values of the solid curve multiplied by 8).

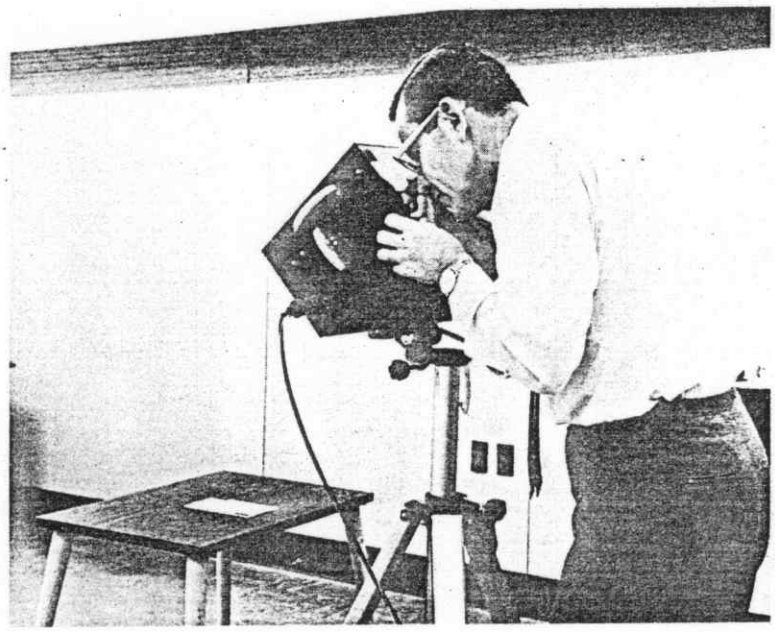


Figure 13.33 The Visual Task Evaluator (VTE) is designed to use 0.2 second exposures that permit more realistic field measurements.

that when persons look up from their desk tasks, the peak of the frequency of their angles of viewings is at 90°, or a horizontal line of sight (28). Thus they look around the room and then back at their desk tasks with their immediate surroundings. This involves looking at various surfaces with their different luminances (brightnesses) as in Figure 13.43. These sudden changes from one luminance to another causes a serious loss of visual sensitivity or visibility unless the luminances are kept within a suitable range of each other (29). The additional contrasts necessary to compensate for losses of sensitivity are plotted in Figure 13.44.

The time-lapse studies show that the relation between the luminance of the background of the details of the task to its immediate and more remote surroundings affects the ability to see the task after looking away from it (Figure 13.45). Furthermore, they demonstrate that the smaller the difference between the brightness of the visual surroundings and that of the visual task, the higher the efficiency of seeing. However equal brightness in all areas of the room would result in a marked feeling of monotony. Investigation has shown that the immediate surroundings should be less bright than the task, but not less than one-third as bright. The luminances of other areas in the field of view should not be less than one-third that of the task and should never be greater than 5 times that of the task. These ratios apply to large areas of the surroundings and can be achieved by the use of ordinary lighting equipment and light-colored room surfaces. (Small areas with accent color do not interfere with the transient adaptation.) Every

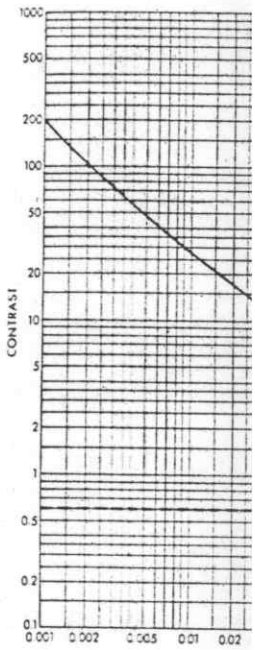


Figure 13.34 Relationship
accuracy, and a field factor

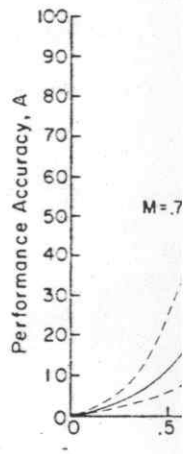


Figure 13.35 Variations in
limits of individual variabilit

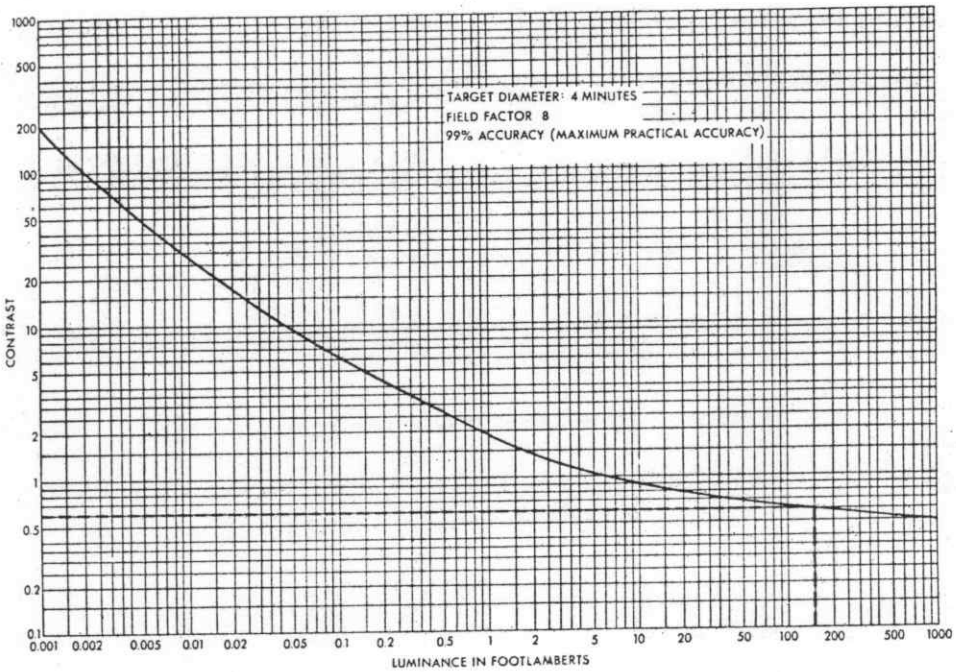


Figure 13.34 Relationship for the standard 4′ target (0.2 second exposure time, 99 percent accuracy, and a field factor 8.00) to which practical tasks ae equated.

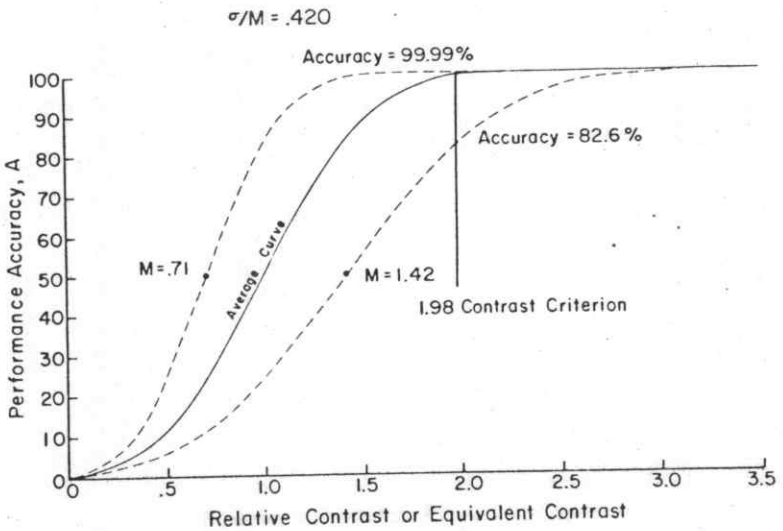


Figure 13.35 Variations in individual accuracy due to variations in *M*.) dashed curves represent limits of individual variability (i.e., limits of young population).

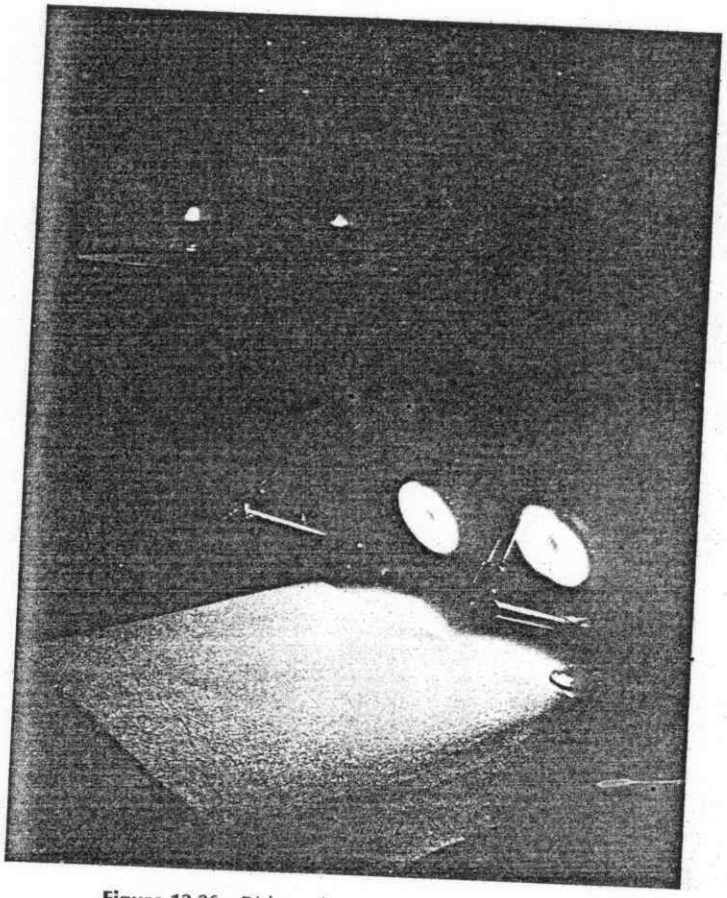


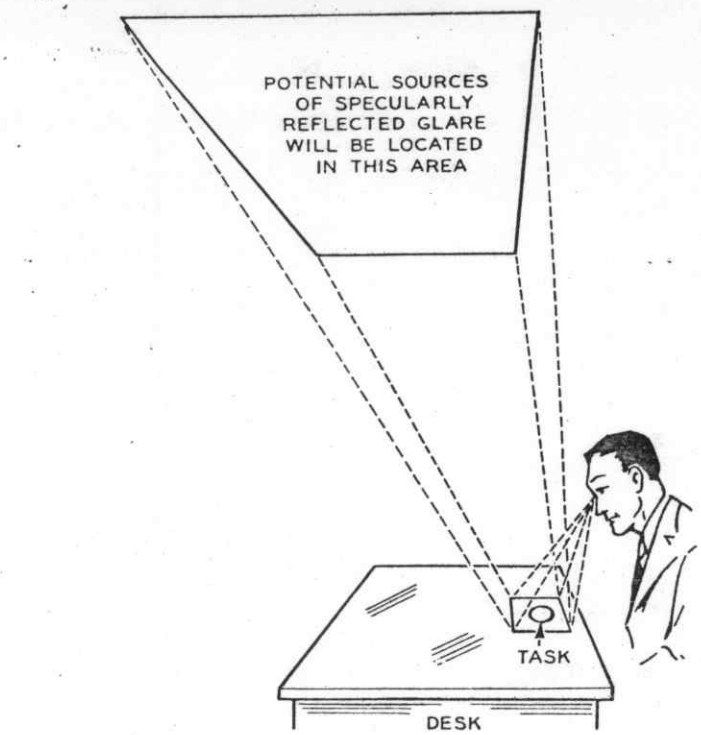
Figure 13.36 Ridges show up under grazing light.

object reflects some portion of the light it receives, and the percentage reflected is known as *reflectance*. The reflectances of floor and furniture should be in the range of 30 to 50 percent, the walls 40 to 60 percent, and the ceiling 70 to 90 percent (Figure 13.46).

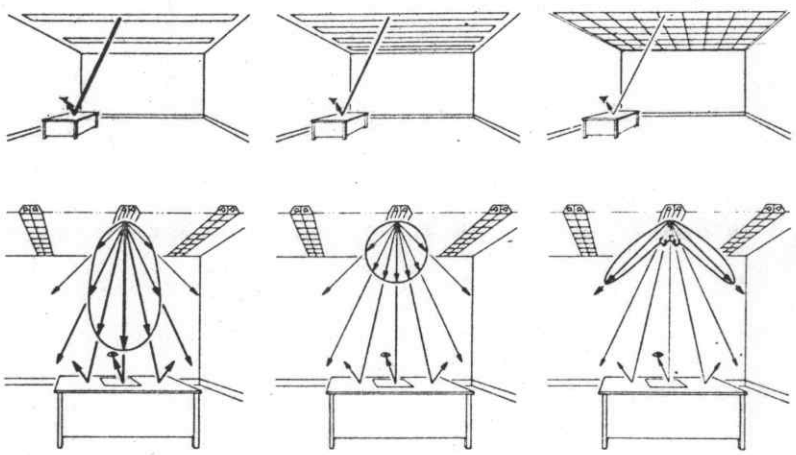
7 ELIMINATION OF DISCOMFORT GLARE FROM OVERLY BRIGHT LIGHTING SYSTEMS

Recently it has been found that the feeling of discomfort is generated in the sphincter muscle controlling the opening of the iris of the eye (30). When one looks up from his or her work and encounters an overly bright lighting system, the sphincter muscle closes down the iris for protection. If one continues to look near the horizontal, the sphincter muscle first closes down too much, then the system desires more light. It opens up too much, and the luminaire overbrightness causes it to close down again. This alternation continues and the phenomenon is called "hippus."

Figure 13.37 (a) A
lighting equipment.
system of fluorescen



(a)



(b)

Figure 13.38 (a) Downward light from luminaires in this zone will cause veiling reflections and serious loss of visibility of office tasks. (*b*) Different luminaire downward components. The less the downward component in the reflection zone of the desk task, the greater the visibility of the task.

1

3

Figure 13.39 Veiling refl
troffer causing veiling refl
Similar situation with letter

An age effect on the li
determined (31). It appe
as the age of the observ
the current recommenda

Research on the sensit
for discomfort glare tha
position of the lighting
number of luminaires in
(32). The result of this r
probability (VCP) for
comfort probability will
room will be satisfied w

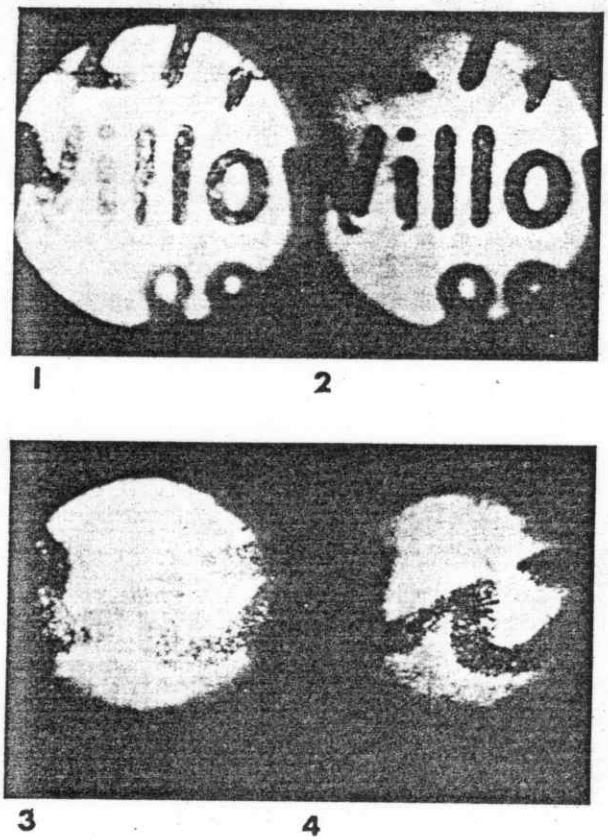


Figure 13.39 Veiling reflections reduce task contrast. (1) Magnified sample of type under a troffer causing veiling reflections. (2) Same sample with veiling reflection shielded out. (3) and (4) Similar situation with letters "a r t" (parts only shown) handwritten in pencil.

An age effect on the limiting luminance at the borderline of discomfort glare has been determined (31). It appears that on the average, the limiting luminance varies inversely as the age of the observer. This may require greater protection for older workers than the current recommendation.

Research on the sensitivity of people to peripheral brightness has developed a formula for discomfort glare that takes into account the luminances of the lighting units, the position of the lighting units in relation to the line of sight, the additive effect of a number of luminaires in the field of view, and the range of sensitivity of the population (32). The result of this research has brought about a standard known as visual comfort probability (VCP) for offices and classrooms. A VCP of 70 means that the visual comfort probability will be such that 70 percent of the occupants at the end or side of the room will be satisfied when the luminances of the luminaires are limited to a given

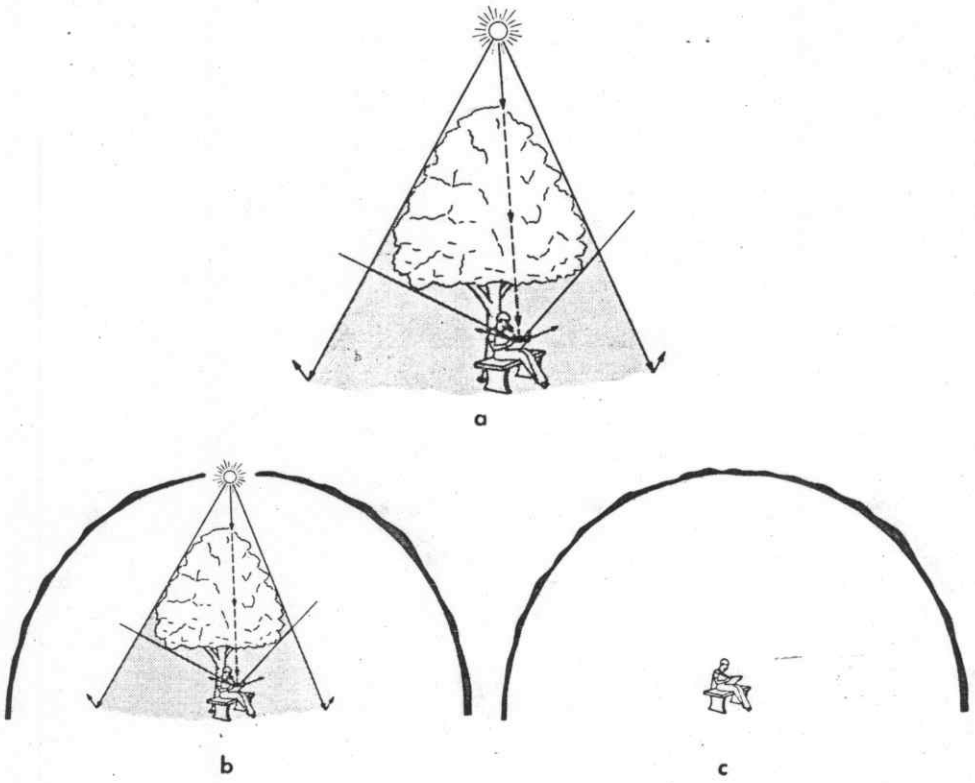


Figure 13.40 (a) Tree shields out veiling light. (*b*) Lights to reading task comes from vault of sky outside veiling zone. (c) Vault of sky with no sun produces good results with low component from the veiling zone overcome by majority of light outside the veiling reflection zone.

value. From a layman's practical viewpoint, this means that when the lighting system is suddenly exposed to view 70 percent of the observers (Figure 13.47) will obtain no shock of overbrightness.

8 DISABILITY GLARE: LOSS OF VISIBILITY

Various researchers (33) have found that a high brightness source away from the line of sight had the same effect in reducing visibility as a uniform veil of brightness overlying the details to be seen on the line of sight. This equivalent veiling luminance is expressed as $L_v = 10\pi[E_1\theta_1^{-2} + E_2\theta_2^{-2} + \cdots + E_n\theta_n^{-2}]$

where L_v = equivalent veiling luminance (footlamberts)
E = illumination on a plane through the center of the pupil perpendicular to the line of sight contributed by each glare source (footcandles)
θ = angular displacement between the line of sight and each glare source

If L_v is put in the
at the resulting contr

where C' = contrast
L_b = luminar
L_o = luminar

The original contrast

The effect of sur
presented in Figures
the background of
increased luminance.
roundings field, there
As an illustration o
consider that one c
approaches the mou
dark hole with no de

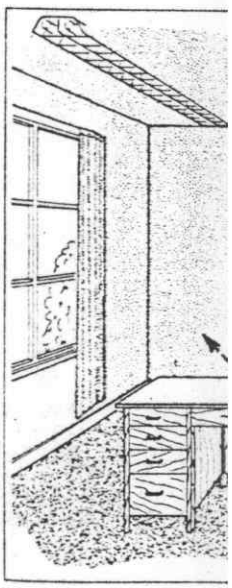


Figure 13.41 Batwing
veiling zone, distributes